Diodes

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Which diode can I use best in my crystal receiver?

Maybe you think a diode with a voltage drop as low as possible, then also small signals at the detector circuit are detected.
But diodes with a low voltage drop, also have a high reverse current (leaking current), this will load the detector circuit heavier, the Q of the detector circuit reduces, and with that also the voltage across the LC circuit.
At a lower input voltage the diode will give much more losses, and it can happen that despite the lower voltage drop of the diode, you have less voltage at the load resistor.
Besides that, reduction of circuit Q will also gives a less selective receiver.

For every 20 mV less voltage drop, the reverse current will approximately double.

Germanium, silicon, en schottky diodes.

Depending on the material they are made from, we can distinguish germanium diodes, silicon diodes and schottky diodes.
There are some more types, which are not discussed here.

Silicon diodes have the highest voltage drop (about 0.5 Volt) and are for this reason not very useable for crystal receivers.
Unless we use a small DC bias current, which brings the diode already a little bit in conduction.

Germanium diodes have a low voltage drop (about 0.1 - 0.2 Volt) and are often used in crystal receivers.
The properties like voltage drop and reverse current can vary a lot between two germanium diodes of the same type.
In practice we can best test several germanium diodes in our receiver and then choose the best.
The diode resistance R_D of germanium diodes is most times rather low, and only useable in crystal receivers with a low Q (low sensitivity and low selectivity).
For high performance receivers, we can better use a suitable schottky diode.

Schottky diodes have a voltage drop of about 0.25 Volt.
The differences in properties between two diodes of the same type are often small.
Schottky diodes with the correct resistance R_D are very useable in high quality crystal receivers.

The given voltage drop is normally measured at a forward current of about 1 mA.
Also if we measure the voltage drop of a diode with a multimeter, the test current shall be about 1 mA.
But also below this voltage drop the diode can conduct current, and can rectify a RF (radio frequency) signal.
Only the current through the diode is then much smaller.
When receiving very weak stations, the current through the diode can be e.g. only 10 nA.
At such a low current, the voltage drop of the diode is also much lower then at 1 mA.

Detected voltage as function of the input voltage

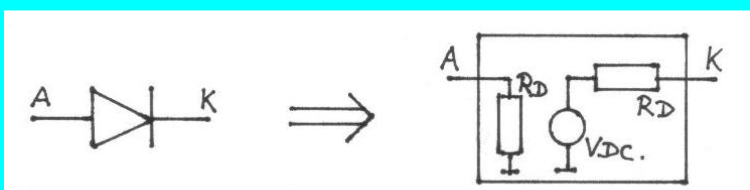
If we rectify a RF signal with a diode we can distinguish two situations.

Situation 1: Rectifying in the linear region
If the input voltage is high enough (well above the voltage drop of the diode at 1 mA), the output voltage of the diode will be about proportional to the input voltage.
So double input voltage, gives about double output voltage.

The output voltage is almost equal to the peak value of the input voltage.
The power losses in the diode are in this region very low compared to the rectified power.

Situation 2: Recifying in the square law region
If the input voltage is low, lower then the voltage drop of the diode (at 1 mA) then the situation is completely different.
The input of the diode behaves for the RF signal like a resistor with value RD.
The output of the diode behaves like a DC voltage source in series with a resistor, the value of this resistor is also equal to RD.
The value of the DC voltage source is square law related to the amplitude of the RF input signal.
So double input voltage, gives 4 times as much detected DC voltage at the output
In the square law region the output voltage of the diode will be much lower then the input voltage, the diode gives much power loss between input and output.
The lower the input voltage, the higher the losses.
The higher the input voltage, the lower the diode losses.
When further increasing the diode input voltage, we gradually come into the linear detection region.
When receiving weak stations, detection takes place in the square law region.

Between the linear and square law region, there is a region not linear, and not square law but somewhere in between.
This region is not discussed here.



Equivalent circuit of a diode at low input voltages.

Via this link you find a measurement on several schottky diodes, which shows detection in the square law region takes place at input voltages below 200 mVpp.

Diode resistance RD.

At zero voltage, diodes have a certain resistance.
This resistance at zero Volt we call RD.
The lower the reverse leaking current of the diode, the higher resistance RD.
When detecting small signals (in the square law region) the input of the diode also behaves like a resistor with value RD.

But how do we know the RD of a diode?
We can calculate it with the formula:
formula 1: **RD = 0.000086171 x n x TK / Is**

RD = diode resistance at zero Volt (unit: Ohm)
n = *ideality factor*, the lower this factor the better, between 1.0 and 1.1 is a very good value.
TK = temperature in Kelvin (= temperature in ºC + 273)
Is = *saturation current* (unit: A)
x = multiply

The values of n and Is can (sometimes) be found in the diode datasheet.

In the following table some types of schottky diodes, with the values for n, Is and Rd, the maximum reverse voltage and the diode capacitance at zero voltage.

type diode	n	Is at 25 ºC	RD at 25 ºC	maximum reverse voltage	capacitance	
5082-2835	1.08	22 nA	1260 kΩ	8 Volt	1 pF	datasheet
BAT85	?	?	± 200 kΩ ??	30 Volt	10 pF	datasheet
HSMS 2820	1.08	22 nA	1260 kΩ	15 Volt	1 pF	datasheet
HSMS 2850	1.06	3000 nA	9.07 kΩ	2 Volt	0.3 pF	datasheet
HSMS 2860	1.10	38 nA	743 kΩ	4 Volt	0.3 pF	datasheet

To decrease the value RD, we can connect more diodes in parallel, with two the same diodes parallel the value of RD shall halve.
With 3 diodes parallel, the value of RD shall be divided by 3 etc..

Diode resistance when using bias current.

We can decrease the value of RD by sending a small DC bias current (e.g. 0.1 uA) in forward direction through the diode.
The higher the bias current, the lower RD will be.
With the following formula we can calculate the diode resistance RD, when we make use of a DC bias current.

Formula 2: **RD = 0.000086171 x n x TK /(Ib + Is)**

RD= diode resistance at certain DC bias current Ib (unit: Ohm)
n= *ideality factor* of the diode
TK = Temperature in Kelvin (= temperature in ºC + 273)
Ib= DC bias current through the diode in A
Is =*saturation current* of the diode in A

A diode with a certain RD value at a certain bias current, gives the same receiving performance as a diode without bias current with the same RD.

Influence of temperature on "saturation current: Is"

The saturation current (Is-value) is strongly depending on temperature.
A temperature increase of 1 ºC will increase the Is value by about 7 %.
In datasheets, the Is value is most times given at 25 ºC.
If the diode temperature is not 25 ºC, but another value "T", then we must multiply Is with a factor 1.07^(T-25).
T = diode temperature
^ = raise to the power of

Ideality factor n

The ideality factor n of a diode indicates how good the diode performs with regard to an ideal diode.
A (not existing) ideal diode has a value of n=1.
At low input signals, the maximum available detected output power is proportional to 1/n.
So doubling the n will halve the output power (this only applies at weak signals).

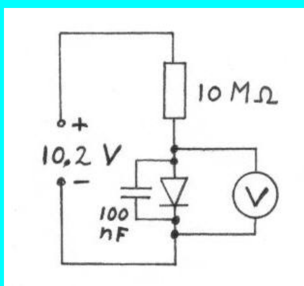
Diode capacitance

Between the two connections of the diode there will be a certain capacitance (capacitor value), when this capacitance is fairly high (e.g. 10 pF) the tuning range at high frequencies is limited.

At increasing reverse voltage across the diode the capacitance will reduce, also the detected voltage in a crystal receiver is such a reverse voltage.
Through this, the frequency of the circuit can shift upwards when receiving strong signals.
On the next page: experiments with a detector unit you find in table 3 a measurement about the frequency shift.

Measuring the Is value of a diode.

We can measure the Is value of a diode as follows:
Send a small current through the diode, the value of this current (I_D) must be about 1 µA.
Measure the voltage across the diode (V_D).



Circuit diagram for measuring the Is value of a diode.
The voltage across the diode is about 0.2 Volt.
The voltage across the resistor is about 10 Volts, so the current is about 1 µA.

The voltmeter must have a resistance of at least 10 MΩ.
The 100 nF capacitor reduces the influence of radio signals and hum on the measurement.

Calculate Is with the formula:

formula 3: **$Is = I_D / (e\^{} (V_D /(0.0257xn))-1)$**

Is = *saturation current* of the diode in nA
I_D = current through the diode in nA, (1 µA = 1000 nA)
e = base of the natural logarithms, this is about 2.718
^ = raise to the power of
V_D = voltage across the diode in Volt
n = *ideality factor* of the diode, if you don't know this value, take for instance: n= 1.08

More information about measuring the Is you can find on the website of Ben Tongue , in his articles number 4 and 16.

I measured the Is value of several diodes, and calculated the diode resistance R_D.
Also some European germanium types are measured.
Several diodes are measured of the type OA95 and AA119

Diode	V_D (Volt) at 1 µA	Is (nA)	R_D (kΩ).
HSMS282K	0.1341	7.9	3428
HSMS282K 2 parallel	0.118	14.5	1867
HSMS286K (1 diode)	0.1116	18.3	1479
5082-2800	0.1871	1.14	23756
5082-2835	0.1464	5.04	5373
5082-2835 2 parallel	0.1289	9.5	2850
BAT 82	0.136	7.3	3710
BAT 85	0.0686	90.8	298
OA81 (germanium)	0.0225	800	34

OA95 #1 (germanium)	0.0272	600	45
OA95 #2	0.0221	821	33
OA95 #3	0.0271	604	45
OA95 #4	0.0304	502	54
AA116 (germanium)	0.0441	256	106
AA119 #1 (germanium)	0.0320	461	59
AA119 #2	0.0363	370	73
AA119 #3	0.0428	272	100

The HSMS282K is the same as the HSMS2820, only the HSMS282K has 2 equal diodes in one package.

The Is value of the HSMS282K, the HSMS286K and the 5082-2835 is lower than the value in the datasheet, this has also been noticed by other people.
Ben Tongue wrote me, that the Is value of the 5082-2835 has been reduced over the years by the manufacturer.
Also temperature has big influence, I measured at 18 ºC, in datasheets the Is value is given at 25 °C.
A increase from 18 °C to 25 °C will increase the Is by 60 %.

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